DOCUMENT RESUME

ED 401 878 IR 018 142

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TITLE Knowledge Acquisition with Static and Animated Pictures in Computer-Based Learning.
PUB DATE Apr 96
NOTE 35p.; Presented at the Annual Meeting of the American Educational Research Association (New York, NY, April 8-12, 1996).
PUB TYPE Reports - Evaluative/Feasibility (142)

EDRS PRICE MF01 Plus Postage. PC Not Available from EDRS.
DESCRIPTORS *Animation; Cognitive Processes; College Students; *Computer Assisted Instruction; Computer Simulation; Foreign Countries; Higher Education; *Hypermedia; Instructional Material Evaluation; Multimedia Instruction; Thinking Skills; *Visualization; *Visual Perception
IDENTIFIERS Germany; *Knowledge Acquisition; Structure Mapping

ABSTRACT

In educational settings, computers provide specific possibilities of visualizing information for instructional purposes. Besides the use of static pictures, computers can present animated pictures which allow exploratory manipulation by the learner and display the dynamic behavior of a system. This paper develops a theoretical framework for analyzing the comprehension of static and animated pictures and for selecting adequate kinds of visualization for instructional purposes. An experiment was performed in which different groups of university students (n=80) had to understand a complex subject matter with the help of computer-based hypertext that contained either static or animated pictures. Results indicate that the structure mapping process is influenced both by the semantic content to be conveyed and by surface characteristics of the picture. The visualization effect is more pronounced with static pictures than with animated pictures. Generally, learners do not use picture information instead of text information and vice versa; instead, text comprehension and picture comprehension stimulate each other. Since animated pictures can present different states of a subject matter, they provide more information to a learner and require more processing than static pictures. Animated pictures reduce the cognitive load of knowledge acquisition, as they provide external support for mental simulations. However, animated pictures may result in a less intensive processing, because they prevent individuals from performing relevant cognitive processes by themselves. Since learners merely have to follow an externally displayed simulation, they may process the subject matter more superficially than they would do with static pictures. (Contains 52 references.) (Author/SWC)

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Knowledge acquisition with static and animated pictures in computer-based learning [1]

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Abstract

Computers provide in educational settings specific possibilities of visualizing information for instructional purposes. Besides the use of static pictures, they can present animated pictures which allow exploratory manipulation by the learner and displaying the dynamic behavior of a system. This paper develops a theoretical framework for analysing the comprehension of static and animated pictures and for selecting adequate kinds of visualization for instructional purposes. Picture comprehension is seen as a bi-directional mapping process between an external visuo-spatial structure and an internal semantic structure of a mental model. Based on this theoretical framework, an experiment has been performed, which aimed at analysing the influence of the kind of visualization and the influence of animating pictures on the cognitive demands of the structure mapping process and the quality of the emerging mental models. In this study, different groups of learners had to understand a complex subject matter with the help of a computer-based hypertext that contained either static or animated pictures, which visualized the subject matter in different ways.

The results indicate, that the structure mapping process is influenced both by the semantic content to be conveyed and by surface characteristics of the picture. Accordingly, the kind of visualization affects the cognitive demands of mental model construction as well as the structure of the emerging model. The computational efficicency of the learner's mental model mirrors the computational efficiency of the presented picture. Animated pictures reduce the cognitive load of knowledge acquisition, as they provide external support for mental simulations. However, this is not necessarily beneficial for learning, because it can prevent individuals from performing relevant cognitive processes by themselves. Since learners can merely follow an externally displayed simulation, they may process the subject matter more superficially than they would do with static pictures. Thus, specific aids are required for learning from animated pictures to ensure that these pictures are processed with sufficient intensity.

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[1] Paper presented at the Annual Meeting of the American Educational Research Association (AERA) in New York, April 8-12, 1996.

1 Introduction

Pictures have played an important role in the field of learning and instruction since a long time. Whereas in the Middle Ages they served primarily to communicate ideas to an illiterate audience, pictures have became not only an aid to the rapidly developing sciences, but also - especially since the work of Comenius (1658) - an essential device to communicate knowledge in educational textbooks. In accordance to the widely held belief, that a picture can be worth more than 10 000 words realistic pictures as well as charts, graphs and diagrams are now unquestioned components of instructional materials. Computers in education provide even more new opportunities to use pictures for instructional purposes. Learners can, for example, be presented animated pictures that display the dynamics of a subject matter. Despite the omnipresence of pictures in teaching and learning, research on knowledge acquisition from visuals is still in its beginnings. Whereas research into language comprehension has made considerable progress in recent decades, we have not attained a deep understanding of why pictures can enhance learning under specific conditions yet (Houghton & Willows, 1987; Kosslyn, 1989, 1995; Larkin & Simon, 1987; Mandl & Levin, 1989; Mayer & Gallini, 1990; Schnotz & Kulhavy, 1994; Weidenmann, 1994; Willows & Houghton, 1987).

The traditional theories on learning from pictures and texts were primarily concerned with the question why pictures enhance retention of learned information. The dual coding theory of Paivio (1971, 1978), for example, assumed two independent, but interacting cognitive subsystems: a verbal system for the processing of verbal information and an imaging system for the processing of pictorial information. According to this theory, words, sentences and texts are usually processed and encoded in the verbal system. Pictures, on the contrary, are encoded both in the imaging system and in the verbal system. Accordingly, the good retention of pictorial information is explained by the advantage of using two codes instead of only single codes (cf. Goetz, Sadoski & Olivarez, 1991; Sadoski, Paivio & Goetz, 1991).

Influenced by the dual coding theory, Kulhavy and his co-workers developed their conjoint processing theory (Kulhavy, Lee & Caterino, 1985; Kulhavy, Stock & Kealy, 1993). In order to explain why maps improve memory for related text information, they assumed a verbal system und an imagery system, which are interrelated by associative links. Their theory gives a special status to the structure information of a map, as this information is assumed to be stored as one memory unit and, thus, requires only a small portion of working memory. Verbal and pictorial information are also thought to be stored as a semantic network and, accordingly, learners who use texts with maps have more possibilities to access the stored information afterwards (cf. Bradshaw & Anderson, 1982; Kerr & Winograd, 1982; Klatzky, Martin & Kane, 1982).

The interplay of texts and pictures in instructional settings has been considered by other authors as a reciprocal compensation for missing information between the two sources of information (Bock & Hörmann, 1974; Molitor, Ballstaedt & Mandl, 1989). According to this view, both pictures and texts contain semantic gaps (i.e. lack specific information), which are filled in with the help of the other source of information. Pictures and texts are considered as complementary

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if an integrated processing of both information sources is required to understand the subject matter.

Unfortunately, these theories suggest only, *that* pictures can be used to enhance learning. In designing instructional material, however, the question is not only whether to use pictures or not. A question of equal importance is which *kind of picture* should be used, or, *how* the respective subject matter should be visualized in a picture. There are frequently various possibilities. If, for example, students should learn that there exist simultaneously different day times and dates at different places on the earth, it would be possible to depict the earth's surface as a rectangle that moves along the time axis like a flying carpet. An example of such a visualization is shown in figure 1. These pictures will be referred to in the following as carpet pictures. Another possibility to display this subject matter would be to imagine the earth as a sphere and portray it as a circle that rotates in a shell of different states of time. An example of such a visualization is shown in figure 2. These pictures will be referred to in the following as circle pictures.

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figure 1 about here

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figure 2 about here

Though the two pictures look very different, they nevertheless include a common set of information. Both of them display time zones, the location of the null meridian, the location of the date line as well as the location of various cities in the world. Accordingly, every information about time differences between the respective locations that can either be extracted from the one picture ore the other picture. In other words: The two pictures are informationally equivalent with regard to knowledge about time differences between locations (cf. Larkin & Simon, 1987).

If knowledge has to be acquired about a dynamic subject matter, computer-based learning provides the possibility not only to use static, but also animated pictures. In the case of static pictures, the learner has to imagine the dynamic of the subject matter - that is, he/she has to simulate the process internally and observe the simulation with the "mental eye". Animated pictures, on the contrary, can display the dynamics of a subject matter directly. Figure 3, for example, shows an animated carpet picture that allows to envision the development of different times and dates on the earth. Figure 4 shows a corresponding animated circle picture. With these pictures, a learner has the possibility to simulate a journey towards the east or the west, to choose among different speeds for the journey, and to observe the respective processes on the screen.

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figure 3 about here

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figure 4 about here

From the perspective of instructional psychology, the question arises which kind of visualization - by carpet pictures or by circle pictures - is better suited for the process of knowledge acquisition. Further, it can be asked, whether animated or static pictures should be used when knowledge about a dynamic subject matter is to be acquired. To answer these questions, however, some more basic questions have to be answered:

- What influence does the visualization format (i.e. the kind of the visualization used in a picture) have on the process and the result of knowledge acquistion?
- Which influence does the use of animated pictures - compared with static pictures - have on the process and the result of knowledge acquistion?

Following, these questions are analysed in more detail. First, a theoretical framework serving to investigate the effects of different visualization formats with static and animated pictures on the process and the results of knowledge acquistion will be developed. Then an empirical study aimed at analysing the effects of different visualization formats as well as the effects of animating pictures on the process and the results of knowledge acquistion will be described. Finally, some theoretical and practical conclusions that can be drawn from the empirical findings will be discussed.

2 Theoretical Framework

As already mentioned above the dual coding theory and the conjoint processing theory can explain why pictures can enhance memory for related text information. However, these theories do not say anything about how to visualize a specific subject matter (cf. Paivio, 1971, 1978; Kulhavy, Lee & Caterino, 1985). In the above mentioned case of time differences on the earth, for example, both the carpet pictures and the circle pictures would result in a dual encoding and, thus, no differences between the two kinds of visualization could be predicted. A similar point can be made regarding the theory of integrative processing of texts and pictures, which assumes that semantic gaps in a text are to be filled in with the help of pictures and vice versa (Molitor, Ballstaedt & Mandl, 1989): If, namely, two different pictures are informationally equivalent, then they contain the same semantic gaps. If these pictures are then combined with texts that are also informationally equivalent, the same amount of integrative processing is to be assumed for both text-picture combinations. Thus, no differences could be predicted here either. Accordingly, also this approach provides no answer to the question which kind of visualization should be used.

Therefore, we have chosen an alternative theoretical framework that appears to be better suited answering the foregoing questions regarding the effects different kinds of pictures in instructional texts have on the process and results of knowledge acquisition. In order to describe this framework, we will first specify which kinds of mental representations are assumed to be created in text processing. Then we will describe, which mental representations play a role in picture comprehension and how these representations are created. Finally, we will characterize texts and pictures as complementary types of presenting information, that contribute in different ways to the acquisition of knowledge.

2.1 Mental Representations in Text Comprehension

Recent theories on human cognition generally assume that comprehension includes the construction of multiple mental representations in the individual's mind (Johnson-Laird & Byrne, 1991). In text comprehension, for example, the reader is assumed to construct (1) a mental representation of the linguistic surface structure, (2) a propositional representation, which preserves the semantic content of the text, and (3) a mental model of the subject matter described in the text (Johnson-Laird, 1983; Morrow, Greenspan & Bower, 1987; Sanford & Garrod, 1981; van Dijk & Kintsch, 1983). Frequently, these models seem to have map-like, characteristics (Denis & Denhiere, 1990; Denis et al, 1994; Ehrlich & Johnson-Laird, 1982; Taylor & Tversky, 1992).

We will focus in the following primarily on the differences between propositional representations and mental models. Propositions are complex mental symbols that are, like sentences and phrases in a natural language, composed of simpler symbols according to specific syntactic rules. Thus, a propositional representation can be viewed as a description of a subject matter in a hypothetical mental language. A mental model, on the contrary, is a hypothetical internal quasi-object, that represents a subject matter on the basis of a structural or functional analogy between the subject matter and the model. Similar to other analogue models the representing characteristics of the model and the represented characteristics of the subject matter can be completely different from one another. Accordingly, mental models are not necessarily pictorial representations of the respective object. They can also represent subject matters that are not immediately accessible to perception (Johnson-Laird, 1983, 1987; Vosniadou & Ortony, 1989).

If text comprehension consists of constructing both a propositional representation and a mental model, this could at the first sight also be considered as a kind of dual encoding. However, this theoretical approach is in fact fundamentally different from the traditional dual coding theory for two reasons. First, a dual coding in the sense of constructing a propositional representation and a mental model is generally assumed not only for pictorial information, but also for text information. Second, the construction of a mental model is not viewed simply as an addition of a further mental code that creates a quantitative advantage compared to a single propositional code. Instead, propositional representations and mental models are thought to employ qualitative different principles of representation that complement one another. Propositions have a

predicate-argument structure which can be considered as arbitrary insofar as they have no similarity with the represented content. As the predicates of propositions are signs for specific relations, propositional representations entail built-in structural characteristics and, thus, can be considered as so-called extrinsic representations (Palmer, 1978). Mental models, on the contrary, represent a subject matter by an analogy. They are based on inherent structural characteristics and can, according to Palmer, be considered as intrinsic representations.

It is assumed that propositional representations and mental models are complementary kinds of mental representations, because each requires the other type of representation to support its own functioning. In text comprehension, for example, readers construct a mental model on the basis of a propositional representation with the help of cognitive schemata. These cognitive schemata function as a description of a typical object or scenario. Accordingly, they give rise to the construction of a corresponding mental model that also represents typical objects or scenarios (Denis, 1982). After a mental model has been constructed, new information can be read from it through inspection of the model. In model inspection an individual detects with the help of cognitive schemata new relations between the mental entities of the model (cf. Pinker, 1990). The new information gained by model inspection is then encoded in terms of new propositions that are added to the propositional representation. Propositional representations and mental models can, therefore, be considered as complementary forms of mental representations that continously interact through schema-driven processes of model construction and model inspection. Within this interaction, propositional representations serve as a basis for mental model construction. The results of model inspection are then in turn encoded in a propositional format (Schnotz, 1993).

2.2 Mental Representations in Picture Comprehension

So far, we have characterized text comprehension as a cognitive process, in which a reader transforms the presented linguistic information into a propositional representation, which in turn guides the construction of the respective mental model. This mental model can then be used to further elaborate the propositional representation. We will turn now to the question what kind of mental representations are formed in picture comprehension and how these representations are constructed.

Pictures can be considered as analog representations - that is, two-dimensional external models - which convey information by the way in which their components are spatially arranged. This means, that both pictures and mental models employ the same principle of representation: the use analogies. Analogy relations are both symmetrical and transitive. Transitivity implies that when (1) a subject matter is analogically represented by an external picture with regard to specific characteristics, and when (2) it also is analogically represented by an internal mental model with regard to the same characteristics, then the same analogy exist between the picture and the mental model. Picture comprehension can therefore be analysed within a theoretical framework that considers the use of analogies as a process of structure mapping (Gentner, 1983; Falkenhainer, Forbus & Gentner, 1989/1990). According to this view, understanding a

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picture is a process of establishing an analogy between the picture and a corresponding mental model. The mental model must be constructed in such a way that (1) specific graphical entities (dots, lines, and so forth) are mapped onto corresponding mental entities and that (2) specific visuo-spatial relations of the picture are mapped onto specific semantic relations of the mental model. This mapping process is directed by so-called graphic schemata: a type of cognitive schemata that represent specific visuo-spatial relations within a graphical display as well as the semantic interpretations of these visuo-spatial relations (Pinker, 1990). In other words, comprehension of a picture can be described as a schema-driven mapping process between an external visuo-spatial structure and an internal, semantically meaningful structure of a corresponding mental model.

The respective mental model can then be used to read off information through processes of model inspection, and this information is again added to the propositional representation. In other words: Both in picture comprehension and in text comprehension a continuous interaction between mental models and propositional representations takes place. On the one hand, mental models are constructed or elaborated on the basis of propositional representations. On the other hand, propositional representations are constructed or elaborated on the basis of mental models, as these models are used to read off new information which is made explicit again in form of new propositions.

The structure-mapping process does not proceed mechanically in a linear order. According to the symmetry of analogies, it can rather proceed in a bidirectional way. That is to say: It is possible to construct a mental model on the basis of a picture, as it is possible to evaluate an already constructed mental model with the help of the respective picture. The mapping process can also be influenced by conceptual knowledge or, for example, by reading a text. In a study performed by Jörg and Hörmann (1978) subjects received simple drawings (e.g., of a flounder and a bread-knife) with either specific sentences (e.g., *"The flounder is lying besides the bread-knife "*) or with general sentences (e.g., *"The fish is lying besides the knife"*). When the subjects received specific sentences, they processed the pictures in more detail than when they received general sentences. This phenomenon could be observed both with the parts of a picture mentioned explicitly in the corresponding sentence and with the non-mentioned parts (Jörg, 1978). Obviously, the mapping between the visuo-spatial structure and the structure of the mental model included more or less details depending on the specifity of the accompanying verbal description. Furthermore, learners can construct different mental representations on the basis of the same picture depending on their expectation of the kind of task (Peeck, 1994; Shepard, 1984; Weidenmann, 1989). In other words. Picture processing can be adapted to the anticipated requirements. The assumtion is that learners can according to their specific aims put more or less emphasis on different parts of a picture's visuo-spatial structure. Thus, their structure mapping process will result in differently elaborated mental models corresponding to the anticipated task requirements.

The structure-mapping view on picture comprehension can be applied both to static and animated pictures. Static pictures present invariant visuo-spatial structures, whereas animated

pictures can also display the transformation of these structures, if the subject matter is a dynamic one. Accordingly, animated pictures can support the construction of dynamic mental models, which can be „run" by the individual as a mental simulation. However, even with such dynamic mental models a structural correspondence between the subject matter and the respective mental model has to exist at specific relevant points during such a mental simulation.

Static pictures convey only structure information. Animated pictures, on the contrary, also display the transformation of structures in time. Thus, they can show the dynamics of the respective subject matter. In short: Animated pictures convey both structure information and process information. Therefore, they give rise to the construction of dynamic mental models, which can be "run" in mental simulations to represent the dynamic of the subject matter (Mayer, 1994). So, animated pictures can supplant the respective cognitive processes, which might be especially helpful to subjects who cannot execute these processes on their own (Salomon, 1994). The structure mapping approach fits, according to our view, both to the comprehension of static pictures and the comprehension of animated pictures, because a structural correspondence between a dynamic subject matter and the respective „running" mental model has to exist at specific relevant moments during this dynamic process.

2.3 Text and Picture Comprehension as Complementary Kinds of Mental Model Construction

According to the considerations presented above, both text comprehension and picture comprehension result in the construction of a mental model. However, the ways of mental model construction are qualitatively different in both cases. Figure 5 shows schematically the different ways to construct a mental model with the help of texts and of pictures. The left part of the figure represents the construction of a mental model by text comprehension. A learner reading a text constructs a mental representation of the text surface (1), forms a propositional representation that captures the semantic content of the text (2), and constructs a mental model on the basis of this propositional representation with the help of cognitive schemata (3). Then this mental model can be used to read off new information by schema-driven processes of model inspection, and this information is added - in a propositional format - to the existing propositional representation (4). This way of mental model construction is a relatively indirect one, as the text is a symbolic extrinsic representation, whereas a mental model is an analog intrinsic representation. So, the principle of representation must be changed, when a mental model is constructed from a text.

The right part of the schema in figure 5 represents the process of picture comprehension. A learner understanding a picture forms via pre-attentive processes a perceptual representation of the picture (5). The visuo-spatial structure of the perceptual representation is then mapped with the help of cognitive schemata onto a mental model with an analog structure that is semantically meaningful (6). This way of mental model construction is a more direct one, because both the picture and the mental model are analog intrinsic representations. In other words: The principle of representation remains unchanged, when a mental model is constructed from a picture. Text

and picture comprehension are qualitatively different ways of constructing a mental model from a subject matter.

figure 5 about here

3 Research Questions

The description of picture comprehension as a mapping of external visuo-spatial structures on internal semantic structures and vice versa provides only a framework that needs further specification. In this paper our main interest is to analyse the effects of different visualizations and the effects of picture animation on the structure mapping process. More specifically, we try to answer the following questions:

- What kind of influence does the visualization format of a picture have on the cognitive demands of the mapping process and the quality of the emerging mental model?
- Does it make a difference in the construction and the quality of mental models if static or animated pictures are presented to the learner?

In the following some hypotheses about the effects of the visualization format and the animation of pictures on the cognitive demands of mental model construction and on the quality of the resulting mental models will be presented.

4 Hypotheses

4.1 Cognitive Demands of Mental Model Construction through Structure Mapping

Effects of Visualization Formats

We assume, that pictures are cognitively processed from a deictic view. That is, they are encoded from an egocentric, observer-related perspective, in which the picture's visuo-spatial configuration is described in a system of coordinates with the observing individual as its origin (Garnham, 1967; Levelt, 1984; O'Brien & Albrecht, 1992). There is a basic difference in this respect between carpet pictures and circle pictures. In carpet pictures, the earth is always seen from the same perspective, which implies that the relations between its graphical entities are stable from the observer's point of view: Anchorage, for example, is always on the left side, whereas Tokyo is always on the right side of the carpet. Therefore, it should be rather easy to relate different carpet picures displaying different daytimes to each other (cf. Bryant & Tversky, 1992; Franklin & Tversky, 1992). The situation is different with circle pictures. Here, due to the rotation of the earth, the earth surface is seen at different times from different perspectives and, thus, the relations between the picture's graphical entities vary from a deictic point of view. Between Anchorage and Tokyo, for example, there is sometimes a right-left-relation, sometimes

a top-bottom-relation, and so forth. Accoringly, it should be more difficult to relate different circle picures displaying different daytimes to each other. Therefore, one can assume that the process of structure mapping between pictures and a mental model is less difficult with carpet pictures than with circle pictures. Accordingly, one can formulate the following hypothesis:

(H1) The cognitive effort required to construct a mental model on the basis of carpet pictures is lower than the cognitive effort on the basis of circle pictures.

While learning about a dynamic subject matter from static pictures, the individual has to mentally simulate the respective dynamic behavior (i.e. run the mental model) on his/her own. Circle and carpet pictures differ in this respect too. With carpet pictures, the simulation corresponds simply to a shift (an object translation) of the carpet along the time axis. With circle pictures, on the contrary, the simulation requires a mental object rotation, which is cognitively more demanding than an object translation (Olson & Bialystok, 1983; Shepard & Hurwitz, 1984; Herrmann, Graf & Helmecke, 1991; Herrmann, Buhl & Schweizer, 1995; Just & Carpenter, 1985). Animated pictures reduce the cognitive load of such simulations, since the learner can observe the respective process in the picture instead of envisioning it by him/herself. Mental rotations being more difficult than mental translations, the use of animated pictures should in the case of circle pictures result in a higher reduction of the cognitive load of mental simulations than in the case of carpet pictures. Accordingly, the difference between carpet and circle pictures regarding the cognitive effort in constructing a mental model should be higher with static and lower with animated pictures. One can, therefore, formulate the following hypothesis:

(H2) The difference between the cognitive effort to construct a mental model with carpet pictures and the effort with circle pictures is higher if these pictures are static, and lower if they are animated.

Effects of Animation

It is difficult to make predictions about the effects of animating pictures per se. On the one hand, animated pictures provide more information to the learner and require this information to be processed by him/her. Accordingly, mental model construction with animated pictures is considered as more demanding than model construction with static pictures. On the other hand, animated pictures provide external support to the construction of a dynamic mental model, that can be "run" in a mental simulation, because these pictures envision the process according to the supplantation principle (Salomon, 1994). In this respect, they reduce the cognitive demands of constructing and using a mental model, because the learner can simply follow an external simulation. Accordingly, animated pictures are also assumed to make the construction of a "runnable" mental model easier than static pictures. As we have no hints, which one of the two effects is stronger than the other, we cannot formulate a general hypotheses about the effects of picture animation on the cognitive demands of mental model construction.

4.2 Quality of Mental Models as a Result of Structure Mapping

Effects of Visualzation Formats

If one is interested in possible effects of the visualization format of pictures on the quality of mental models, an essential distinction has to be made, namely whether one views mental models as being fundamentally different from pictorial representations or whether one ascribes partially pictorial characteristics to these models (cf. Garnham, 1987; Johnson-Laird, 1983). If one assumes that mental models are fundamentally different from pictorial representations, one can presume that only those parts of a picture's structure that carry semantic information enter into the mental model construction. Semantically irrelevant pictorial surface characteristics will then not be mapped onto the mental model. In this case, different pictures will result in the same mental model structure as long as the pictures are informationally equivalent. If one, however, assumes that mental models possess pictorial characteristics, one can expect that not only the semantically relevant content of a picture, but also the semantically irrelevant surface characteristics are mapped on the mental model. In this case, different kinds of pictures will result in different model structures, even when the pictures are informationally equivalent.

Of course, the question arises how it is possible to test such structural assumptions about the respective mental models. As Palmer (1978) has pointed out, a representation includes only as much information as can be extracted from it with available procedures. One should, however, not only look for the informational content of a representation, but also for its computational efficiency, that is, how easy or difficult it is to perform the specific procedures and to extract the respective information from the representation (Larkin & Simon, 1987). As the computational efficiency of a representation is assumed to be a function of its structure, one has the possibility to draw conclusions about the structure of a representation from its computational efficiency for specific tasks.

What differences are to be expected from the above mentioned case of various daytimes and days on the earth? An individual who is learning about this topic can be asked different kinds of questions. One possibility would be to ask questions regarding time differences between specific locations on the earth as, for example, *"What is the time in Anchorage, if it is Thursday 9 o'clock p.m. in Tokyo?"*. They will be referred to in the following as "time differences questions". One can assume that such questions can be better answered with carpet pictures than with circle pictures. In a carpet picture, places that are located far apart from each other (horizontally) are also separated by a big time difference, whereas places that are located close to each other only have a small time difference between them. In a circle picture, on the contrary, places can be located in direct proximity and yet be separated by a big difference in time (if they are located closely to the eastern and western side of the so-called dateline). If picture comprehension entails mapping of surface characteristics onto the emerging mental model, the computational efficiencies of models constructed from different pictures should correspond to the computational efficiencies of the respective pictures. Accordingly, one can formulate the following hypothesis:

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(H3) Time difference questions can be answered more easily with mental models constructed from carpet pictures than with models constructed from circle pictures.

An individual learning about different daytimes and days on the earth could also be asked about temporal phenomena related to trips around the world. Such a question could be, for example, *"Why did Maghellan's companions think, upon their arrival after sailing around the world, that it was Wednesday when it was actually already Thursday?"* We will refer to these questions in the following as „circumnavigation questions". One can assume that such questions can be better answered with circle pictures than with carpet pictures, because with a circle picture one can imagine a circumnavigation as a continuous circular movement. With a carpet picture, on the contrary, one has to leave the carpet at one side upon crossing the date line and simultaneously re-enter the carpet at the opposite side. It is supposed that these discontinuities in the envisioning of a circumnavigation might be a source of difficulties for learners. Therefore, if picture comprehension entails mapping of surface characteristics onto the emerging mental model, one can assume that mental simulations of a circumnavigation can be more easily performed with mental models constructed from circle pictures than with models constructed from carpet pictures. Accordingly, one can formulate the following hypothesis:

(H4) Circumnavigation questions can be answered more easily with mental models constructed from circle pictures than with models constructed from carpet pictures.

Effects of the Animation

Static pictures display only an invariant visuo-spatial structure. They support the construction of a mental model, but not the "running" of the model by mental simulations. So, mental simulations have to be performed without external support. Animated pictures, on the contrary, support the construction of a mental model as well as the respective mental simulations. In other words: They can have a supplantation function in the construction of a dynamic mental model (Salomon, 1994). If animated pictures allow exploratory manipulations by the learner, they can also make more aspects of the subject matter obvious than static pictures. They, therefore, display a higher amount of information to the learner, since they explicitly present different states of the subject matter which otherwise would have to be inferred. Accordingly, learning with animated pictures can be assumed to result in more elaborated mental models, which are easier to be "run" in a mental simulation process than models constructed from static pictures. As such models are assumed to be advantageous for answering both time difference questions and circumnavigation questions, one can formulate the following hypotheses:

(H5) Time difference questions can be answered more easily with mental models constructed from animated pictures than with models constructed from static pictures.

(H6) Circumnavigation questions can be answered more easily with mental models constructed from animated pictures than with models constructed from static pictures.

To test these hypotheses the following experiment was performed.

5 Method

Subjects and learning material. Subjects were 80 university students, randomly assigned to four groups of 20 subjects each. Every subject was presented a computer-based hypertext consisting of 2750 words. The text included 22 paragraphs about the following topics: *division of the earth into time zones* (6 paragraphs), *different times of day on the earth* (5 paragraphs), *different dates on the earth* (7 paragraphs), and *date zones on the earth* (4 paragraphs). Four text versions were used in the experiment. In two versions, the text paragraphs were associated with carpet pictures. In the two other versions, the paragraphs were associated with circle pictures. Within each pair, one version included static and the other one animated pictures. Contrary to the static pictures, the animated pictures allowed a simulation of the course of time and an exploratory manipulation of the depicted subject matter. Within each text version, the subjects had free access to the text paragraphs and pictures via a hierarchically organised menu.

With regard to time differences between the cities shown on the maps, the static carpet pictures and circle pictures were informationally equivalent. Every information about time differences between these locations that could be extracted from a static carpet picture could also be extracted from the corresponding circle picture, and vice versa. Similarly, the animated carpet pictures and circle pictures were also informationally equivalent. In the different text versions reference was made to the respective pictures, which required minor linguistic variations. The information about the subject matter, however, remained the same. Insofar, the different text variants could also be considered as informationally equivalent.

Procedure. The study consisted of a pretest phase, a practice phase, a learning phase, and a posttest phase. In the pretest phase, the subjects were given a test of prior knowledge, in which they were to explain a series of concepts referring to time phenomena on the earth. In the practice phase, they were made familiar with operating the computer-based hypertext system, using other learning material. In the learning phase, all subjects received a series of questions about time phenomena on the earth as an orientation aid for their learning activities. These questions included both time difference questions and circumnavigation questions. The subjects were then instructed to answer the questions on the basis of the available text and picture information. The subjects in the four groups received different text versions with different pictures according to a 2x2 factorial design. The factors were *visualization* (carpet vs. circle pictures) and *animation* (static vs. animated pictures). The subjects were further instructed that they would be tested afterwards for their comprehension of the learning material. Finally, n the posttest phase, subjects had to apply the acquired knowledge in a comprehension test consisting of 35 multiple-choice items. The test included both time difference and circumnavigation questions. Subjects had to answer these question without any access to the learning material.

Scoring. In analysing the results of the pretest, subjects were given knowledge points for correct statements about the presented concepts. During the learning phase, the frequency of access to each text paragraph and the frequency of access to each picture was automatically registered. In analysing the posttest, the number of correctly answered time difference questions and the number of correctly answered circumnavigation questions were determined.

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6 Results

The average prior knowledge score was 6.35 (SD=2.25) for the static carpet group and 6.65 (SD=3.05) for the static circle group. The respective values for the animated carpet group were 5.17 (SD=2.54) and 6.11 (SD=3.31) for the animated circle group. A 2x2 analysis of variance for the prior knowledge scores with the factors *visualization* and *animation* yielded no significant effects. Insofar, we can assume that the four subject groups were comparable to each other.

In order to find out whether the effects of the factors *visualization format* and *animation* are dependent on the learners' prior knowledge, the whole group of subjects was divided into two groups based on a median split. One group of subjects had lower prior knowledge, and the other group had higher prior knowledge. The following analysis of the results is therefore based on 2x2x2 ANOVAs including the factors *visualization* (carpet/circle), *animation* (static/animated) and *prior knowledge* (lower/higher).

6.1 Cognitive Demands of Mental Model Construction

The cognitive demands of mental model construction might be reflected by the use of picture information and the use of text information. Accordingly, one can assume that learners use pictures in a cognitively demanding mental model construction more frequently than when the model construction is relatively easy. Similarly, one can assume that learners read a text paragraph more frequently if mental model construction is difficult, because more intensive guidance of mental model construction is required, than if the construction process is easy. Therefore, the subjects' frequencies of access to pictures and their frequencies of access to text paragraphs were used as indicators for the cognitive demands of mental model construction.

The average frequencies of access to static and to animated carpet and circle pictures are shown in figure 6. Whereas the average frequency of access to static carpet pictures was only 13.2 (SD=6.0) it was 19.1 (SD=12.6) for the static circle pictures. The respective values were 15.9 (SD=6.3) for the animated carpet pictures and 14.7 (SD=5.9) for the animated circle pictures. Figure 7 presents the average frequencies of access to text paragraphs in the different groups. The mean frequency of access to text paragraphs was only 21.8 (SD=13.2) when learners had static carpet pictures, whereas it was 34.8 (SD=23.4) when the subjects had static circle pictures. The respective values were 28.6 (SD=16.7) for the subjects with animated carpet pictures and 28.9 (SD=13.5) for those with animated circle pictures.

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figure 6 about here

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figure 7 about here

The results of the analyses of variance for the frequency of access to pictures and for the frequency of access to text paragraphs are presented in table 1. There was a tendency of accessing circle pictures more frequently than carpet pictures ($F(1,72)=2.12$; $p<.10$). As the interaction *visualization x animation* indicates, this difference was significantly more pronounced with static than with animated pictures ($F(1,72)=3.35$; $p<.05$). Accordingly, the corresponding a priori contrast between the static carpet and the static circle group showed a significant difference in the frequency of access to pictures ($t(38)=1.90$; $p<.05$), whereas no such difference was found between the animated carpet and circle group (see figure 6).

Tab. 1: Results of ANOVAs for access to pictures and for access to text paragraphs by visualization, animation, and prior knowledge.

	Access to Picture Information		Access to Text Information	
Visualization	$F(1,72)=2.12$	$p<.10$	$F(1,72)=3.29$	$p<.05$
Animation	$F(1,72)=0.52$	n.s.	$F(1,72)=0.01$	n.s.
Prior Knowledge	$F(1,72)=2.01$	n.s.	$F(1,72)=0.84$	n.s.
Visualization x Animation	$F(1,72)=3.35$	$p<.05$	$F(1,72)=2.64$	$p=.055$
Visualization x Prior Knowledge	$F(1,72)=0.00$	n.s.	$F(1,72)=0.03$	n.s.
Animation x Prior Knowledge	$F(1,72)=0.02$	n.s.	$F(1,72)=0.26$	n.s.
Visualization x Animation x Prior Knowledge	$F(1,72)=0.21$	n.s.	$F(1,72)=0.36$	n.s.

The analysis of variance for the frequencies of access to text information showed a significant effect of the *visualization* factor: Subjects who had learned with circle pictures showed significantly higher frequencies of access to the text paragraphs than subjects who had learned with carpet pictures ($F(1,72)=3.29$; $p<.05$). This effect also seems to be more pronounced with static pictures than with animated pictures, since the respective interaction *visualization x animation* nearly reached the 5%-level of significance ($F(1,72)=2.64$; $p=.055$). Accordingly, the a priori contrast between the static carpet group and the static circle group showed a significant difference in the frequency of access to text information ($t(38)=2.15$; $p<.05$), whereas there was no such difference between the animated carpet group and the animated circle group (see figure 7).

6.2 Quality of Mental Models

In order to answer the question whether the visualization format and the animation of a picture influences the quality of the learners' mental models we analysed the subjects' answers on the time difference questions as well as their answers on the circumnavigation questions in the final comprehension test. The average numbers of correctly answered time difference questions of subjects with static and with animated carpet and circle pictures are shown in figure 8. On the average, the static carpet group solved 9.25 items correctly (SD=2.95), whereas the static circle group only had a mean number of 7.50 correctly solved items (SD=2.31). Subjects using animated carpet pictures on the average solved 10.7 items correctly (SD=3.18), and for the animated circle group the number of correctly answered items was 10.2 (SD=3.50).

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figure 8 about here

The results of the ANOVA for the performance of solving time difference tasks are presented in table 2. We found a significant effect of the factor *visualization* ($F(1.72)=2.94$; $p<.05$) and a highly significant effect of the factor *animation* ($F(1,72)=9.63$; $p<.01$). Subjects who had learned with carpet pictures performed significantly better on time difference tasks than subjects who had learned with circle pictures. Subjects who had learned with animated pictures performed highly significantly better than subjects who had learned with static pictures.

We also found a significant interaction between *visualization* and *prior knowledge* ($F(1,72)=4.04$; $p<.05$). The corresponding mean performances of subjects from the carpet

Tab. 2: Results of ANOVAs for performance in solving time difference tasks and circumnavigation tasks by visualization, animation, and prior knowledge.

	Time Difference Tasks		Circumnavigation Tasks	
Visualization	$F(1,72)=2.94$	$p<.05$	$F(1,72)=6.70$	$p<.01$
Animation	$F(1,72)=9.63$	$p<.01$	$F(1,72)=0.64$	n.s.
Prior Knowledge	$F(1,72)=1.35$	n.s.	$F(1,72)=0.85$	n.s.
Visualization x Animation	$F(1,72)=1.62$	n.s.	$F(1,72)=1.08$	n.s.
Visualization x Prior Knowledge	$F(1,72)=4.04$	$p<.05$	$F(1,72)=1.74$	n.s.
Animation x Prior Knowledge	$F(1,72)=0.52$	n.s.	$F(1,72)=0.07$	n.s.
Visualization x Animation x Prior Knowledge	$F(1,72)=0.01$	n.s.	$F(1,72)=1.09$	n.s.

group and those from the circle group with lower and with higher prior knowledge are shown in figure 9. On the average, subjects with lower prior knowledge answered 10.32 time difference questions correctly (SD=3.56), when they had seen carpet pictures before, whereas they answered only 7.83 items correctly (SD=3.35) when they had previously seen circle pictures. The corresponding a priori contrast showed a significant difference ($t(38)=2.25$; $p<.05$), whereas there was no such difference among learners with higher prior knowledge. On the average the carpet group solved 9.50 items correctly (SD=2.48), and in the circle group the respective value was 9.68 (SD=2.95).

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figure 9 about here

The average numbers of correctly answered circumnavigation questions are presented in figure 10. The subjects who had been presented the static circle pictures showed a mean number of 10.10 correctly anwered circumnavigation questions (SD=3.01), whereas the subjects who had been presented the static carpet pictures answered only 7.80 of these items correctly (SD=2.33). Subjects who were presented the animated circle pictures solved 8.90 circumnavigation tasks correctly (SD=2.53). In the animated carpet group the respective number of correctly answered items was 8.05 (SD=2.96). The results of the analysis of variance for the performance in solving circumnavigation tasks are presented above in table 2. We found a highly significant effect of the factor *visualization*. Accordingly, subjects who had learned with circle pictures performed much better than those who had learned with carpet pictures ($F(1,72)=6.70$; $p<.01$). There were no further significant effects found in this analysis.

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figure 10 about here

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7 Discussion

Visualization and the Cognitive Demands of Mental Model Construction

The reported frequencies of access to picture information and to text information during the learning phase support hypothesis (H1) about the cognitive demands of mental model construction. Accordingly, the cognitive effort required to construct a mental model on the basis of carpet pictures is lower than the cognitive effort associated with circle pictures. There seem to be two reasons for this effect: First, the earth depicted as a carpet is always seen from the same perspective, whereas depicted as a a circle it is seen from different perspectives. Second, a mental translation is easier than a mental rotation. More generally, the results support the assumption that the format of visualization affects the cognitive demands of mental model construction.

The data also support hypothesis (H2). Accordingly, the differences in the demands of mental model construction due to different visualization formats are more pronounced in the case of

static pictures than in the case of animated pictures. With static pictures of a dynamic subject matter, the learner has to perform mental simulations without external support, whereas animated pictures allow him/her to observe and follow the respective process. So, the cognitive demands of mental simulations (in our case: of a translation versus a rotation) are more important in learning from static pictures than in learning from animated pictures.

The data about the access frequencies also have implications regarding the interplay between text and picture comprehension. As mentioned above, pictures and texts have sometimes been viewed as complementary sources of information, because both sides can contain semantic gaps (i.e. lack specific information) which are to be filled in with the help of the other side (Molitor, Ballstaedt & Mandl, 1989). The data presented above clearly contradict this view about the interplay between text and picture comprehension. The circle pictures and the carpet pictures in our experiment were informationally equivalent with regard to the learning task (i.e., every task-relevant information could be extracted from one kind of picture as well as from the other kind of picture), and the respective texts were also informationally equivalent. Accordingly, the same amount of integrative processing should be assumed for the text with carpet pictures and the text with circle pictures. However, the subjects in fact accessed not only the picture information, but also the text information more frequently when they learned with circle pictures than when they learned with carpet pictures. Obviously, they did *not* use the picture information *instead of* the text information, or vice versa. The cognitively more demanding mental model construction with circle pictures has apparently triggered a more intensive text processing, and this more intensive text processing might have resulted again in a more intensive study of the respective pictures. In other words: The relation between text comprehension and picture comprehension has been a mutual stimulation rather than using one kind of information instead of the other kind of information.

Visualization and the Structure of Mental Models

The data about answering time difference questions and circumnavigation questions in the final test phase gave support to both hypothesis (H3) and hypothesis (H4) regarding the influence of the visualization format on the structure of the emerging mental model. On the one hand, subjects could answer time difference questions with mental models constructed from carpet pictures better than with models constructed from circle pictures. On the other hand, circumnavigation questions could be answered better with mental models constructed from circle pictures than with models based on carpet pictures. Thus, the results support the assumption that the surface structure of a picture affects the structure of the learner's mental model.

The effect of the visualization format on the structure of a mental model does not seem to be the same for all learners. As the significant interaction between *visualization* and *prior knowledge* regarding the answering of time difference questions indicates, the effect was significantly more pronounced when subjects had low prior knowledge than when they had high prior knowledge. A possible interpretation could be that learners with high prior knowledge are less dependent in

their model construction on the specific kind of visualization. More specifically, it could be assumed that they are able to construct a carpet model also from a circle picture and a circle model also from a carpet picture. In other words: Learners with high prior knowledge could be able to construct different kinds of mental models from the same kind of picture and use different models for different requirements. On the contrary, learners with low prior knowledge could be more bound to the specific visualization presented to them.

Though this seems to be a plausible interpretation for the interaction *visualization x prior knowledge* regarding time difference tasks, this interpretation turns out to be problematic since it does not fit to the other data. If learners with high prior knowledge would be less dependent on the specific kind of visualization, one would expect the same kind of interaction with regard to circumnavigation tasks. However, there was no such interaction. So, the question arises why there was a significant interaction effect with time difference tasks, but no such interaction with circumnavigation tasks.

We assume that learners with high prior knowledge were already familiar with carpet pictures.They probably already had a carpet model in their mind before the learning process. Accordingly, these learners could answer time difference question rather easily even when they had seen circle pictures before and, thus, performed as well as learners who had been presented carpet pictures. Low prior knowledge subjects probably did not already have a carpet model in their mind and, thus, were disadvantaged when they had to answer time difference questions after having been presented circle pictures instead of carpet pictures. This would explain why a significant difference in answering time difference questions was found when subjets had low prior knowledge, whereas no such difference could be observed with high prior knowledge subjects.

Nevertheless, learners could have been generally quite unfamiliar with circle pictures. Accordingly, they did not have already a circle model in their mind before learning, regardless whether they had low or high prior knowledge. Thus, in order to answer circumnavigation questions, all learners had to engage in constructing a circle model. Accordingly, both learners with low and learners with high prior knowledge might have been equally disadvantaged when answering circumnavigation questions after having seen carpet pictures instead of circle pictures. This would explain why a significant main effect for the factor *visualization* was found regarding the circumnavigation questions, whereas no interaction between *visualization* and *prior knowledge* could be observed.

Animation of Pictures and the Quality of Mental Models

Regarding the effects of animation, the data of the subjects' performance in the comprehension test supported hypothesis (H5), but not hypothesis (H6). Subjects who had learned with animated pictures were better in answering time difference questions, yet were not better in answering circumnavigation questions than those who had learned using static pictures. This

raises the question, under which conditions animated pictures enhance the construction and use of mental models.

One possible reason for the different effects of picture animation might have been the different task requirements. Answering time difference questions required knowledge about the exact time coordinates of different cities. Subjects had to know, for example, that the time in Anchorage is always 10 hours earlier than the time in Greenwich. Circumnavigation questions, on the contrary, did not require such detailed information. They rather required an adequately structured mental model that could be used for mental simulations. Since animated pictures can present explicitly different states of the subject matter, they contain more information than static pictures. In our study, subjects with animated pictures had the opportunity to create different states of time and, accordingly, to pick up more detailed information about time differences than subjects using static pictures. Therefore, learners who had used animated pictures might have performed better in answering time difference questions, because they had encoded more detail information than learners who had used static pictures.

But why did the animation of pictures not have a positive effect on answering circumnavigation questions? Animated pictures provide not only support to mental model construction, but also to mental simulations. On the contrary, static pictures support only mental model construction, but do not enhance mental simulations. Therefore, since answering circumnavigation questions requires mental simulations, one can expect - as done in hypothesis (H6) - that learning with animated pictures will result in higher performance. This explanation seems plausible, but it nevertheless only takes into account the information provided to the learner and does not consider how he/she really deals with this information.

There were in fact indications of remarkable differences between static and animated pictures with regard to information processing. As the data about frequencies of access to picture information had indicated, static circle pictures were used significantly more frequently than static carpet pictures (see figure 6). This corresponds to hypothesis (H1), that carpet pictures are easier to process than circle pictures. However, as the significant interaction *visualization x animation* had shown, the situation was quite different with animated pictures. Here, the carpet pictures were not used less frequently than the circle pictures, as the frequency of access to carpet pictures had increased due to the animation, whereas the frequency of access to circle pictures had decreased.

The increased frequency of access to carpet pictures due to the animation corresponds to the assumption that animated pictures provide more information to the learner and, thus, require more processing than static pictures. But why did the frequency of access to circle pictures decrease as a result of the animation? As assumed above, animated pictures do not only support the construction of a mental model, but also mental simulations. As the learner can simply observe and follow the respective processes with animated pictures instead of envisioning these processes by him/herself, the animation reduces the cognitive load of such simulations. Furthermore, it was assumed that a mental simulation of the earth's movement is more difficult with circle pictures than with carpet pictures, because a mental rotation is cognitively more

demanding than a mental translation. Accordingly, the cognitive load of a mental simulation should be more reduced by an animation of circle pictures than by an animation of carpet pictures. This could explain why the frequency of access to circle pictures decreased as a result of the animation. If animated pictures reduce the demands of cognitive processing, then this could result in a more superficial learning, because the subjects no longer have to perform the mental simulations on their own. This might be a disadvantage especially with tasks that require mental simulations such as, in our study, the circumnaviation questions. Therefore, the lack of a positive effect of picture animation on answering circumnavigation questions could be explained by a more superficial processing of animated pictures, since the learners did not need to perform the respective mental simulations on their own during the learning phase.

So apparently, it is not necessarily helpful for learning if performing a mental simulation is made easier with the help of animated pictures. On the one hand, the animation enables some individuals to perform mental simulations that these learners otherwise were unable to do. On the other hand, however, the animation can result in a more superficial processing, because the learners have only to follow an externally displayed simulation process. With static pictures, on the contrary, learners have to perform the respective simulation process by themselves. Accordingly, there are not only positive effects to be expected from learning with animated pictures. The negative effects might for example be that learners engage in a less intensive processing of the subject matter, because the animated pictures allow them to observe the respective processes without much cognitive effort.

8 Summary

The results of this study indicate that the format of visualization used in a picture affects the cognitive demands of the structure mapping process during picture comprehension and, thus, affects the required cognitive effort for the construction of a mental model. As far as the influence of the visualization format is due to different cognitive demands of mental simulations, the visualization effect is more pronounced with static pictures than with animated pictures. The results indicate that not only the task relevant semantic content of a picture, but also surface characteristics, that are not semantically relevant, are included in the structure mapping process. Accordingly, the surface structure of a picture affects the structure of a learner's mental model, and the computational efficiency of the emerging mental model for specific tasks corresponds to the computational efficiency of the picture. Furthermore, the results show that generally learners do not use picture information instead of text information and vice versa. Instead, text comprehension and picture comprehension rather stimulate each other, as a more intensive processing of the text triggers a more intensive processing of the pictures and vice versa.

Since animated pictures can present different states of a subject matter, they provide more information to the learner and require more processing than static pictures. Animated pictures reduce the cognitive load of knowledge acquisition, as they provide external support for mental simulations. However, this is not necessarily beneficial for learning: Whereas some individuals might with this external support be able to perform mental simulations they were otherwise

unable to do, other learners perform a less intensive processing of the subject matter than if they had static pictures. In other words: Animated pictures may result in a less intensive processing, because they prevent individuals from performing relevant cognitive processes by themselves. Since learners merely have to follow an externally displayed simulation, they may process the subject matter more superficially than they would do with static pictures.

9 Theoretical and Practical Consequences

A theory of visual learning should not only suggest whether pictures are to be used in teaching and learning or not. It should also make assertions as to how a subject matter should be visualized, that is, which visualization is most appropriate for a specific purpose. The results of this study indicate, that the theoretical approach presented in this paper might be a useful framework for this purpose, as it allows to analyse the effects of different visualizations on knowledge acquisition and on the resulting knowledge structures. According to this approach, picture comprehension is a process of mapping between an external visuo-spatial structure and a internal semantic structure of a mental model. The kind of visualization used in a picture affects the difficulty of the mapping process as well as the structure of the emerging mental model. Accordingly, predictions can be made about the required cognitive effort of mental model construction and about the usefulness (i.e. computational efficiency) of the emerging mental model for specific tasks. One can therefore make decisions about the adequacy of different kinds of visualization for various purposes. The structure mapping approach to picture comprehension therefore seems to be more promising than the traditional theories, which provide no basis for such predictions and decisions.

Under a practical perspective, the study presented above indicates that pictures in learning material need careful design. It is not sufficient to ask which semantic content is to be communicated. It has also to be addressed, how easy or how difficult the process of structure mapping is when a particular kind of visualization is used, that is, whether the mental model construction requires lower or higher cognitive effort. Finally, it should be asked what is the use of the acquired knowledge after learning. Since the structure of a mental model constructed by a learner is influenced by the structure of the presented picture, the computational efficiency of this visuo-spatial structure for the future tasks can be used to decide on the most adequate kind of visualization. If the acquired knowledge is to be used for different purposes, mental model construction should not only be based on one kind of picture. Instead, learners should be presented different kinds of visualizations in order to enhance the construction of different mental models. Furthermore, the respective pictures should be systematically referred to one another, so that learners can construct a coherent system of different mental models and flexibly switch between them according to the task at hand.

Animated pictures can be helpful for learning, as they not only support mental model construction, but also mental simulations. Learners can observe externally displayed processes which they would not be able to perform mentally on their own. However, there is also a danger with animated pictures that individuals are prevented from performing relevant cognitive

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processes by themselves and, thus, process the subject matter more superficially than with static pictures. So, it appears that specific aids are required for learning from animated pictures to ensure that these pictures are processed with sufficient intensity.

The theoretical approach proposed in this paper should of course be tested by further studies with different learning contents, different kinds of visualization, different kinds of animation, different learning tasks, and different subjects. If the basic assumptions are confirmed, this will be not only theoretically relevant, but will also give practical guidance for the use of pictures in the field of instructional design.

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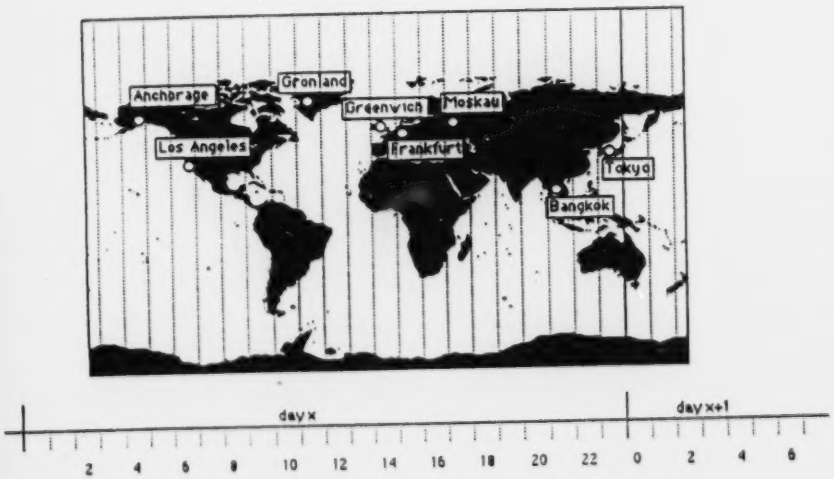
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day x
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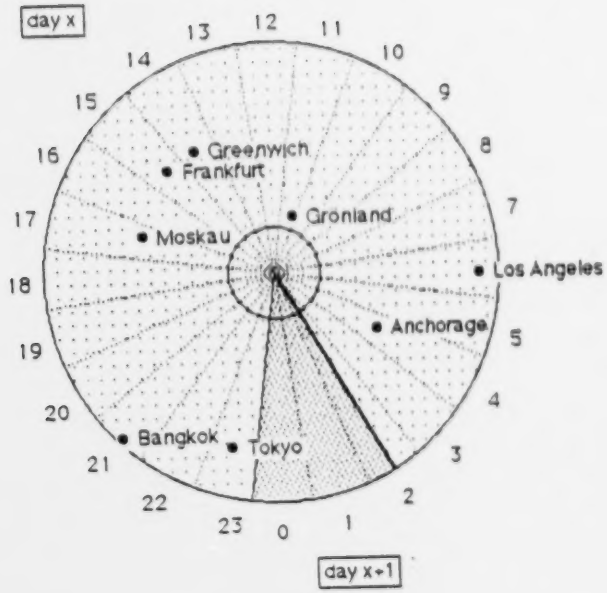
Fig. 1


day x
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Moskau
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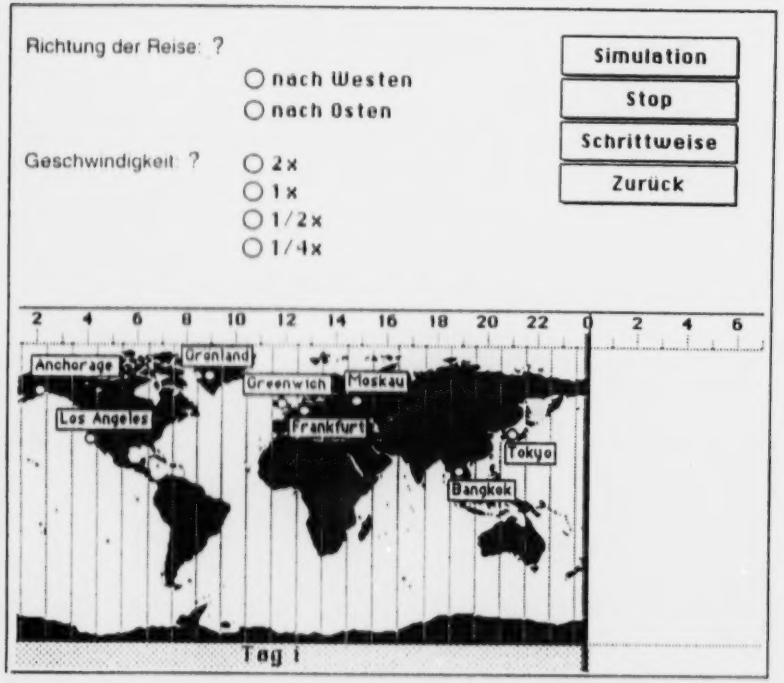
Bangkok
Tokyo
day x+1

Fig. 2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nach Westen
nach Osten
Geschwindigkeit: ?
2x
1x
1/2x
1/4x
Simulation
Stop
Schrittweise
Zurück
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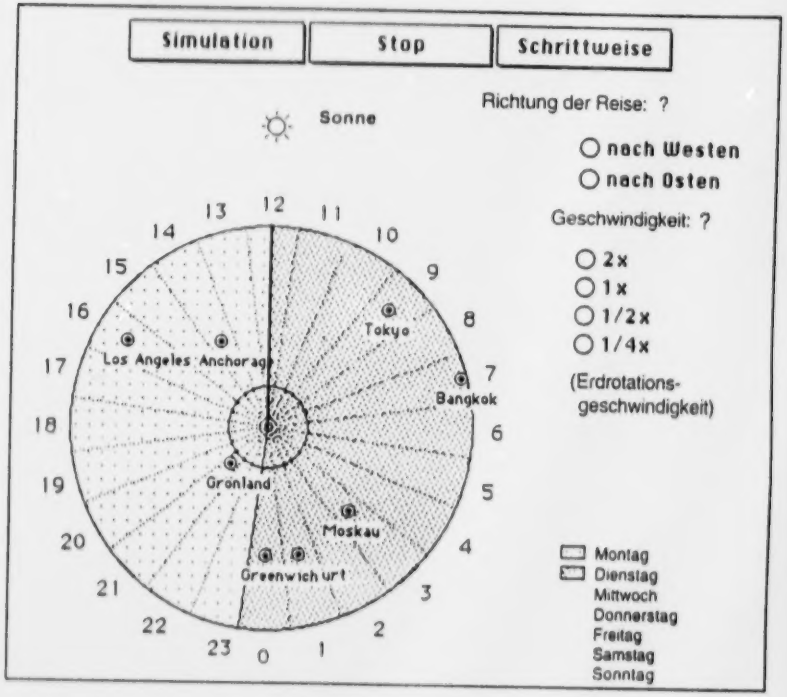
Anchorage
Grönland
Greenwich
Moskau
Los Angeles
Frankfurt
Tokyo
Bangkok
Tag

Fig. 3


Simulation
Stop
Schrittweise
Sonne
Richtung der Reise: ?
nach Westen
nach Osten
Geschwindigkeit: ?
2x
1x
1/2x
1/4x
(Erdrotations-
geschwindigkeit)
12 11 10 9 8 7 6 5 4 3 2 1 0 23 22 21 20 19 18 17 16 15 14 13
Tokyo
Los Angeles
Anchorage
Bangkok
Grönland
Moskau
Greenwich urt
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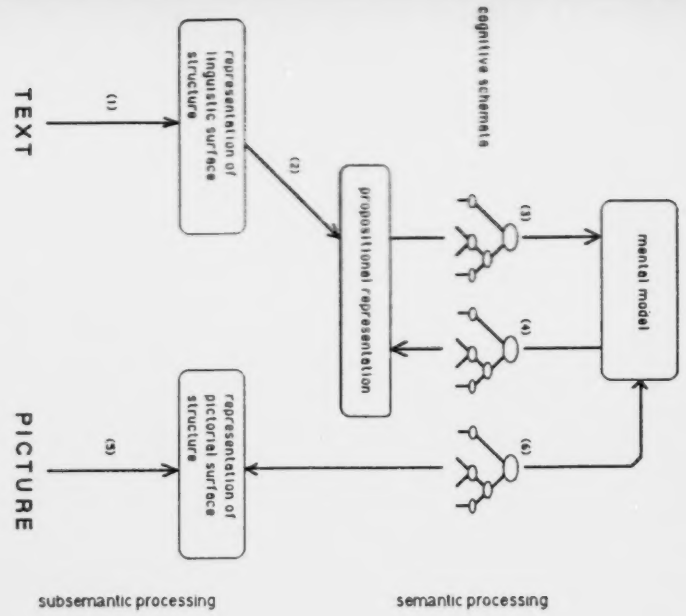
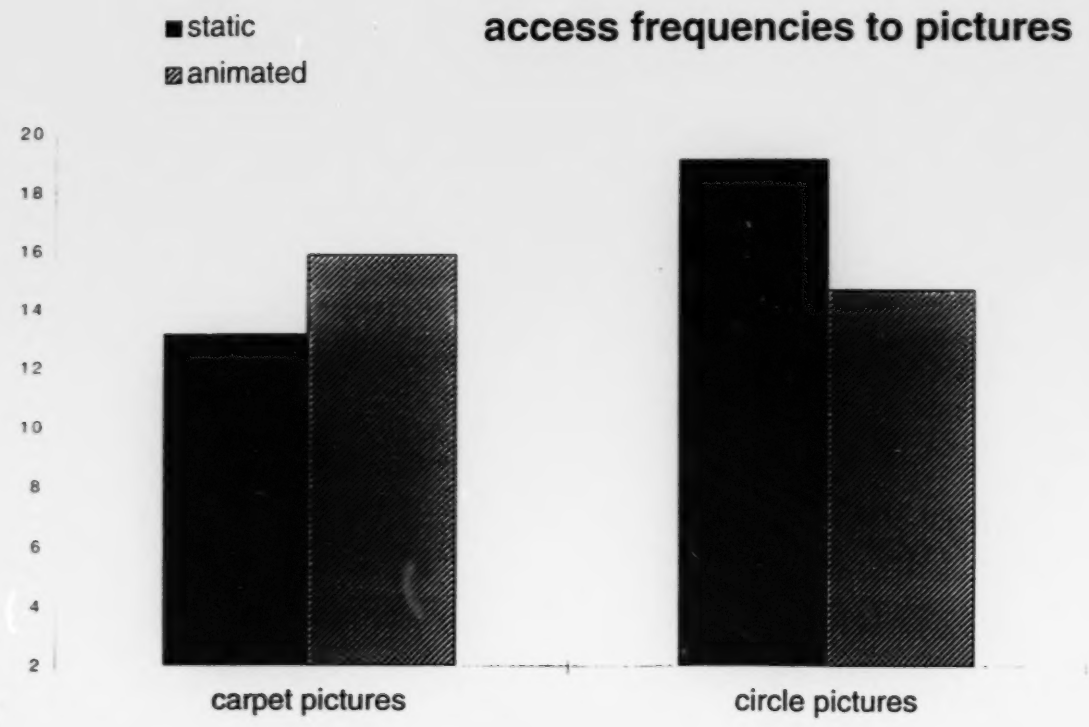
Dienstag
Mittwoch
Donnerstag
Freitag
Samstag
Sonntag

Fig. 4

Fig 5





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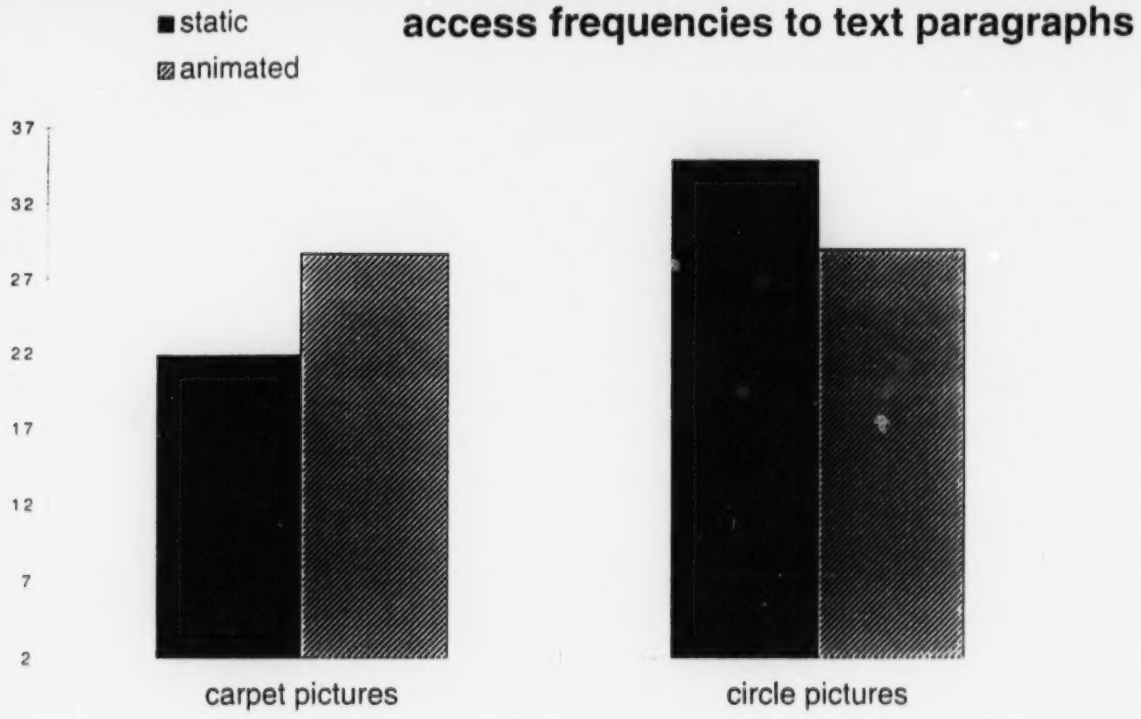

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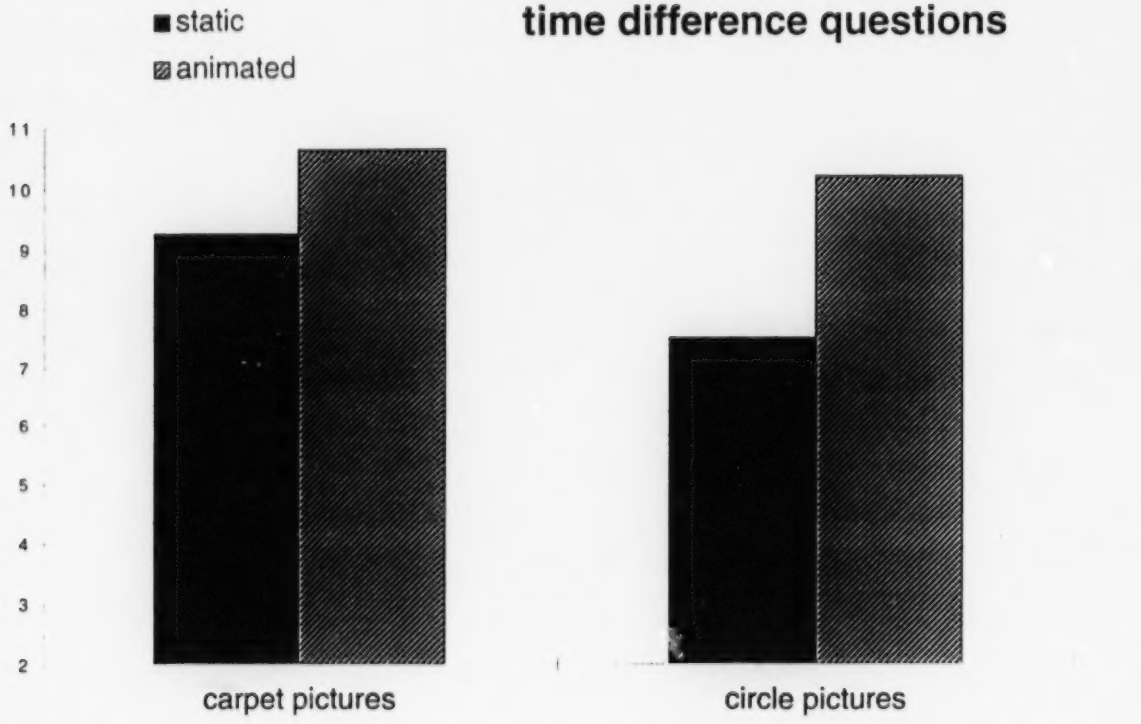

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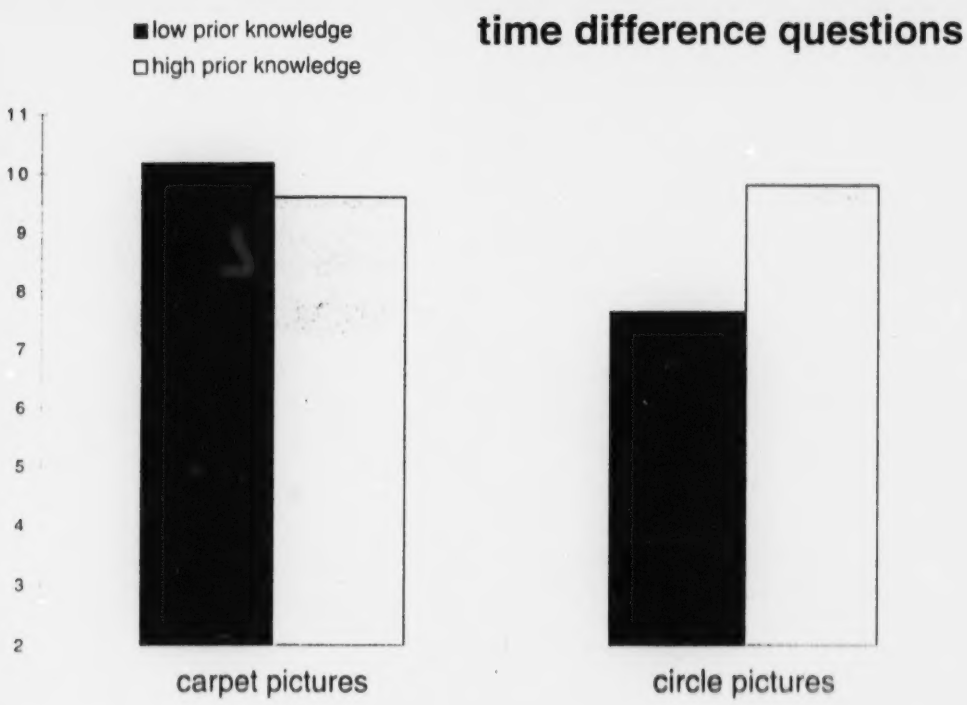

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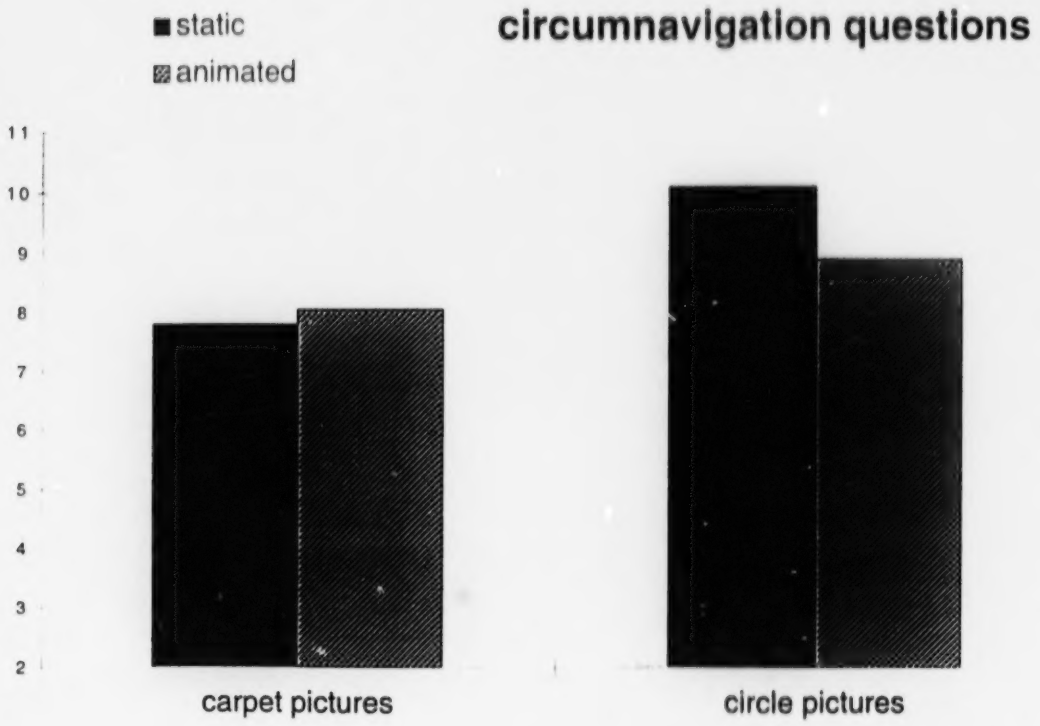

Figure 10